



Dynamics of canopy development of *Cunninghamia lanceolata* mid-age plantation in relation to foliar nitrogen and soil quality influenced by stand density

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ABSTRACT

It has been generally accepted that different silvicultural practices affect the forest canopy morphology and structure. During forest establishment, many natural sites were converted to coniferous plantations in southern China. Retention of the canopy during stand conversion may be desirable to promote ecological function and meet conservation objectives. We tested the impact of planting density, foliar nitrogen and soil chemical properties on the canopy development of Chinese fir (*Cunninghamia lanceolata*) mid-age monoculture stands. Low density (1450 trees hm^{-2} with planting spacing of 2.36×2.36 m), intermediate-density (2460 trees hm^{-2} with planting spacing of 1.83×1.83 m) and high density (3950 trees hm^{-2} with planting spacing of 1.44×1.44 m) stands were selected in Xinkou forest plantations in Sanming City, China. Canopy characteristics such as leaf area index (LAI), mean tilt angle of the leaf (MTA) and average canopy openness index (DIFN) were measured. Measurements were taken using LAI-2200 PCA. The results illustrated that stand density was the primal factor responsible in canopy structuring while soil chemical properties seem to play a secondary role for canopy dynamics. LAI increased from $3.974 \text{ m}^2 \text{ m}^{-2}$ to $5.072 \text{ m}^2 \text{ m}^{-2}$ and MTA increases from 34.8° to 48.7° as the stand density increased while the DIFN decreased from 0.1542 to 0.0902 with the increasing stand density but it was no significantly different in intermediate and high-density stands. Additionally, LAI and MTA were positively correlated to foliar nitrogen while the DIFN was negatively correlated. In general, soil available nitrogen, available phosphorus and soil pH were not significant to canopy parameters. The results presented provide guiding principles about the canopy dynamics distribution in varying stand densities from LICOR measurements in mid-age Chinese fir monoculture. Furthermore, this provides a base to study canopy dynamics at mature stage forests because of more senescence activities.

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1. Introduction

Tree plantations are a significant part of the forest ecosystems of China and Chinese fir (*Cunninghamia lanceolata* (Lamb) Hook) is the most planted species in these plantations (Farooq et al., 2019a). Chinese fir is a typical evergreen sub-tropical coniferous timber tree species (Yu, 1997). Its main characteristics are high yield, excellent timber quality and fast growth (Tian et al., 2011; Wu et al., 2017). Its planting area covers over 11 million ha, which accounts for about 6% of all the plantation forests of the world, and 18.2% of the area in China (State forestry administration 2014; Farooq et al., 2019b). Considering the vast area under plantation, Chinese fir plantations also play a vital role in providing habitat for native biota (Dymond et al., 2015), climate regulation, and soil and water conservation (Yao et al., 2015); additionally, it is also used as biomass energy (Huang et al., 2013). Since the 1980s, Chinese fir plantations with shorter rotation cycle (15–20 years) has led to a decrease in its production (Ma et al., 2007; Farooq et al., 2018). Furthermore, increasing cultivation also encourages the shortening of the fallow period in the cultivation cycle resulting in the degraded lands, which directly affect productivity (Mizuno et al., 2013).

Canopy characteristics estimation is a measurement of crucial importance in forest ecosystems (Davi et al., 2008). It is used for understanding the rates of energy and material exchange between plant canopies and atmosphere (Cohen et al., 2003; Fournier et al., 2003). Canopy characteristics can be measured and analyzed from individual tree crowns to a whole stand even to entire regions to continents (Asner, 1998; Clark et al., 2008). It is an important structural characteristic for determining the impacts of planetary climatic changes on forests (Thomas and Winner, 2000) and an essential quantity due to the biomass production or health status evaluation, because it is highly associated with growth range from the plot to the globe (Fownes and Harrington, 1990). Moreover, it has a strong relation with forest transpiration because the leaf area index is proportional to canopy conductance for water vapor (Suyker and Verma, 2008).

Canopy size is often measured as leaf area and the canopy size can determine the productivity of the forest stands due to its role in radiation interception (Landsberg et al., 1996; Barbier et al., 2010). Along with the environmental and edaphic factors like precipitation, water availability, elevation, temperature, soil fertility and topography, the canopy is also influenced by different silvicultural practices such as planting density and spacing, and genotype of trees. For example, intensive thinning and pruning of crown due to stem density can dramatically influence canopy dynamics due to the availability of radiation to individual trees, which can transform the crown structure or stand as a whole (Khairiah et al., 2017). Furthermore, varying stand density and spacing induce various growth competition stress for trees.

The improvement of soil quality through different means is considered as a sustainable silvicultural practice. Soil quality structures the distribution of the forest and paves the way for new plantations to grow, creating an environmental heterogeneity. Therefore, it plays a crucial role in making and changing the structure of tree stands and renewing the forest (Muscolo et al., 2007a, 2007b). The canopy effect and soil effect are related to each other. The soil, an essential part of the forest ecosystem in which nutrients are recycled and many microorganisms live, is influenced by the forest canopy. Soil phosphorus (P) and nitrogen (N) fractions appear to be affected by canopy structure and gaps (Hu et al., 2016; Scharenbroch and Bockheim, 2008a). Moreover, undisturbed closed forest, lowers the amounts of labile carbon and rates of soil respiration also decreased with the increase in canopy gap (Cheng et al., 2014; Scharenbroch and Bockheim, 2008b). The soil effect involves the variations that vegetation produces on physical, chemical and biological soil properties. Many studies have revealed that woody species can increase the organic matter and soil nutrients because of the litter accumulation beneath their canopies.

To learn about this development, knowledge about the effects of different silvicultural practices of forest management on the canopy dynamics of monoculture plantations is obligatory. The objective of our current research was, 1) to analyses the impact of different competition stress levels on the characteristics of canopy dynamics (Leaf areas index (LAI), mean tilt angle of the leaf (MTA), and average canopy openness index (DIFN) of *Cunninghamia lanceolata* by providing different stand densities and spacing, 2) and to examine the correlation of canopy characteristics with stand density, soil nutrients and foliar nitrogen. LAI-2200C instrument was used for this experiment.

1.1. LAI-2200C instrument

Canopy dynamics can be estimated using different experimental methods such as indirect, direct, semi-direct and subjective-evaluation methods (Jonckheere et al., 2004). Even though it is widely believed that, direct destructive measurements are more accurate way than indirect optical measurements, however, the LAI-2200 (LI-COR Inc., Lincoln, NE, USA) system has proven to provide canopy dynamics values closest to those obtained with the direct method (leaf harvest methods) (Sandmann et al., 2013). "LAI-2200C instrument integrates a fish-eye optical sensor with five silicon detectors arranged in circular rings that sample radiation above and below canopy at five zenith angles simultaneously" (Fig. 1) (Ilangakoon et al., 2015). Its measurements are acquired by leveling and viewing the sky, where detector 1 measures brightness directly overhead. The transmittance of below canopy reading was normalized by corresponding above canopy reading to calculate LAI.

Although LAI means "leaf area index," but the LAI-2200C measures all light-blocking objects using a plant canopy analyzer. LAI-2200C analyzer is a passive sensor and one of the commonly used instruments for the LAI measurement attributes from radiation measurements (Sandmann et al., 2013). In terms of accuracy, flexibility and advanced features, it outperforms other methods such as hemispherical photography and ceptometry. It measures the values in different illumination conditions

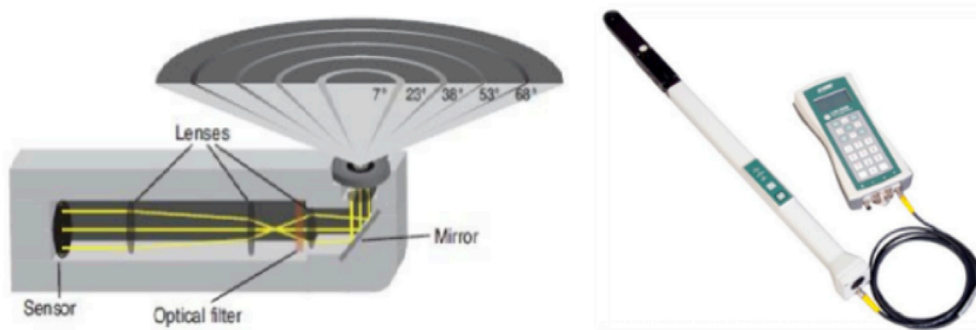


Fig. 1. LICOR PCA LAI-2200 sensor and its schematic composition (Photo taken from LAI-2200 manual).

without being restricted by lighting conditions and no direct sunlight is required for measurement. It is used in measuring different sizes of canopies from small grass to a large forest (Pearse et al., 2016).

2. Materials and methods

2.1. Study site and plantation establishment

The proposed study was conducted in the Chinese fir plantations established in Xinkou forest farm in Sanming City, Fujian Province of PR China, located at 26°10'N, 117°27'E with the elevation range of 205–500 m from the sea level. Three young to mid-age (11-year-old) Chinese fir monoculture stands were selected; those were planted for the study purpose in 2007 (Fig. 2). Surface biomass was burned before establishing plantation stands and one-year-old seedling was used for planting. The understory vegetation of stands was composed of herbs and shrubs (e.g., *Callicarpa kochiana*, *Alpinia japonica*, *Maesa japonica*, *Selaginella moellendor*, *Ilex pubescens*, and *Woodwardia japonica*). The climatic condition of the study area mentioned in (Table 1).

According to the research objectives, low density (1450 trees ha⁻¹ with planting spacing of 2.36 × 2.36 m- D1), intermediate-density (2460 trees ha⁻¹ with planting spacing of 1.83 × 1.83 m- D2) and high density (3950 trees ha⁻¹ with planting spacing of 1.44 × 1.44 m- D3) stands were selected. Three 20 × 20 m experimental plots were selected in each stand density, making it a total of nine plots. In each plot, diameter at breast height (DBH) and height of trees were taken. Within each density stand, data was taken from 15 different locations making a total of 45 locations. We tried to select only those areas where any kind of visible natural or human disturbance was very less.

Data about the soil physio-chemical properties and soil nutrients reported in our published article (Farooq et al., 2019c) (Table 2). Leaf biomass distribution is shown in (Fig. 3a and b); moreover, complete detail about tree growth (Table 2), biomass production and distribution among different tree components are reported in our published article (Farooq et al., 2019b).

2.2. Data collection

All the measurements were conducted by using the verified methodology (Pokorny et al., 2000; Ilangakoon et al., 2015; Moser et al., 2015). Measurements were taken in October 2018 with the LAI-2200 system in the remote mode below the canopy; by simultaneous readings above the forest floor at 2 m height with 2–5 m distance between measurement points (Pokorný and Stojnič, 2012), and in nearby open areas for above canopy reading (Moser et al., 2015). Canopy measurements of all points above and below canopy readings were taken. The most accurate measurements were collected during the overcast sky conditions (Ilangakoon et al., 2015). Measurements were taken close to sunset and sunrise in the case of bright (clear) sky, when in the open plot, the radiation readings of the first LAI-2000C ring sensor changed from 3 to 30 and vice versa. Within each stand, transects were distributed evenly and perpendicularly oriented to tree-rows or along the level curves depending on stand structure.

To exclude the operator from the viewing area, the 90° of azimuthal view was restricted in all measurements below low canopies. Using the interpolation method of the above-canopy readings, the calculation of the effective leaf area index (LAI_e) from the LAI-2200 C direct measurements was implemented by the PC program C2200.exe (LI-COR, USA). All LAI_e values were re-calculated with the masking of the last two rings (i.e., 5th and 4th rings; 47–74° of zenithal view). A correction factor of 1.6 was multiplied to LAI_e to obtain hemi-surface LAI (i.e., half of the total needle surface area normalized by the ground area). As the stand was young, we used a correction factor of 1.6 as it was found appropriate for young stand (Pokorny and Marek, 2000). For the visible proportion of the sky, a Diffuse Non-interceptance ~ canopy openness (DIFN) value by means of a sensor used for canopy coverage quantification or forest homogeneity, as a by-product of LAI-2200 C, mentioned in LAI-2200 operating manual.

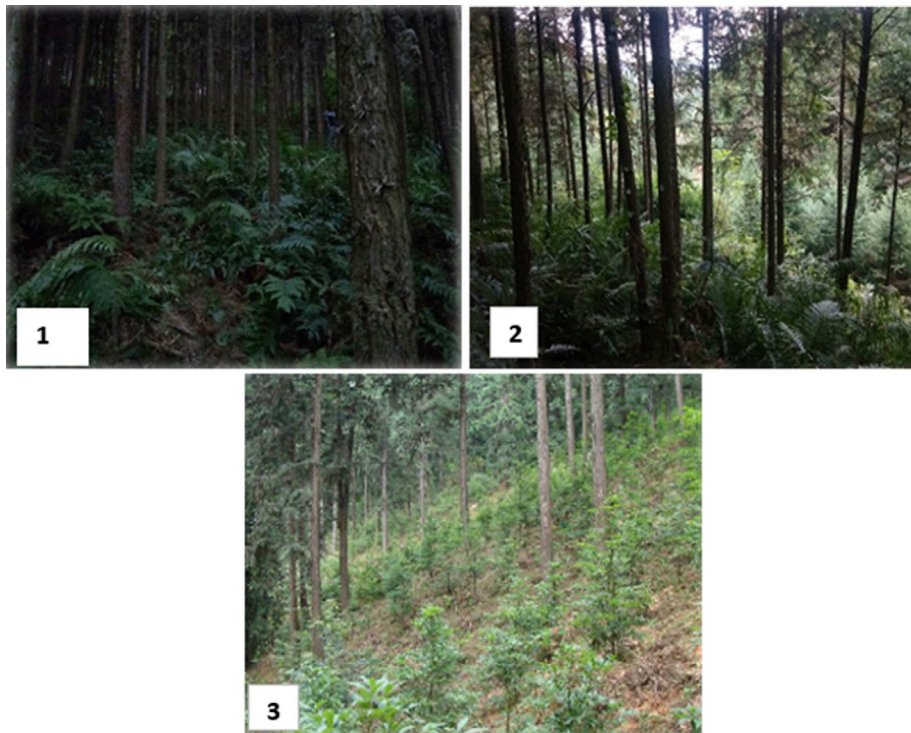


Fig. 2. Information about the study site, 1 = high density stands, 2 = intermediate density stands and 3 = low density stands in Xinkou *Cunninghamia lanceolata* forest plantation in Sanming, Fujian, PR China.

Table 1

Climatic condition of the study area (Koppen-Geiger climate classification).

Parameter	Value	
Climate	Sub-tropical	moon-soon
Average annual temperature	19.3 °C	—
Maximum temperature	33.3 °C	July
Minimum temperature	3.8 °C	January
Annual precipitation	1612 mm	—
Maximum precipitation	279 mm	May
Minimum precipitation	40 mm	December
Annual humidity	82%	—
Soil type	Acidic	—
Soil classification	Silty Oxisol	USA soil taxonomy

Table 2

Soil pH, soil nutrients, average height, average mortality and mean diameter at breast height in low, intermediate and high density Chinese fir stands. Values are mean \pm SE.

	Low density	Intermediate density	High density
Soil properties			
Available N (mgkg ⁻¹)	67.69 \pm 2.2 a	59.04 \pm 3.0 ab	54.07 \pm 1.9 b
Available P (mgkg ⁻¹)	3.92 \pm 0.2 c	5.16 \pm 0.4 a	4.79 \pm 0.5 b
Available K (mgkg ⁻¹)	87.23 \pm 2.1a	81.44 \pm 3.9b	87.30 \pm 5.4a
Soil pH	4.21 \pm 0.04 b	4.31 \pm 0.03 a	4.27 \pm 0.03 a
Average height (m)	12.46 \pm 0.14a	12.01 \pm 0.3a	11.63 \pm 0.23a
Mean diameter (cm)	13.05 \pm 0.12a	12.46 \pm 0.43a	11.04 \pm 0.19b
Average mortality (%)	8.37%b	9.69%b	11.99%a

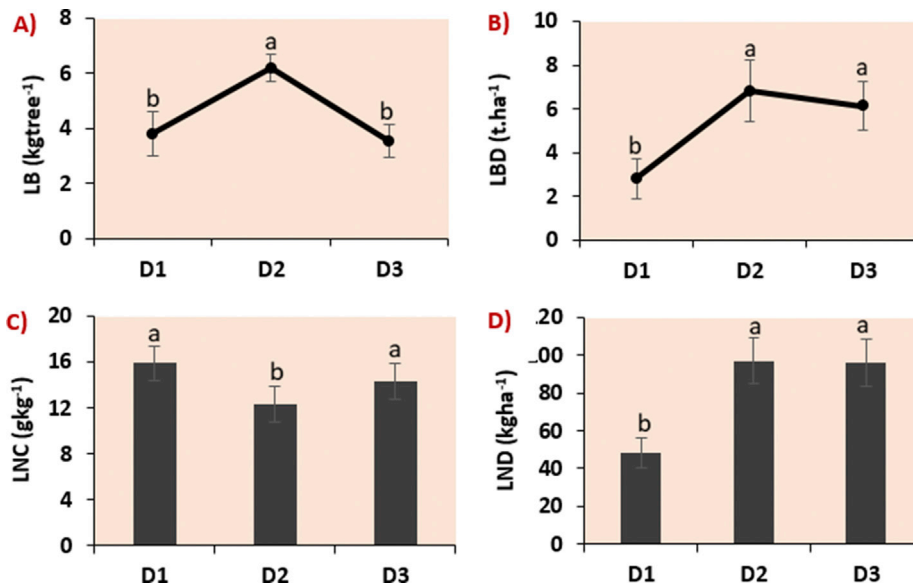


Fig. 3. (A) Leaf biomass (LB), (B) leaf biomass distribution (LBD), (C) Leaf nitrogen concentration (LNC) and (D) leaf nitrogen distribution (LND) in low (D1), intermediate (D2) and high-density (D3) stands of Chinese fir. Values are mean \pm SE of five replicates. Different letters exhibit the statistical difference at $P < 0.05$.

2.3. Statistical analysis

One-way analysis of variance (ANOVA) with the least significant difference (LSD) multiple comparison test was used to determine the variations among studied parameters. Pearson correlation test (two-tail) was conducted to identify the relationship of canopy dynamics with leaf nitrogen and soil nutrients. A regression analysis was used to see the relationship between the response variables and independent variables. Results were statistically analyzed using a $p < 0.05$ level of significance. All statistical analyses were conducted using SPSS Statistical Package (SPSS 19.0, SPSS Inc., IL, U.S.A.). ArcGIS software was used to make the study area map. Origin 9.1 and MS excel soft-wares were used to create graphs.

3. Results

3.1. Foliar nitrogen

Leaf N content decreased from low to intermediate-density stand but increased in high-density stand. Overall, a significant difference ($F = 14.42$, $P = 0.04$) was observed among low, intermediate and high-density stand. It was observed $16.92 \pm 0.78 \text{ g kg}^{-1}$ in low, $13.51 \pm 1.12 \text{ g kg}^{-1}$ in intermediate while $15.93 \pm 1.32 \text{ g kg}^{-1}$ in the high-density stand. In terms of leaf N distribution, there was no significant difference found between intermediate and high-density stand, while both were significantly different from the low-density stand. Its values were $82.80 \pm 12.5 \text{ kg ha}^{-1}$, $85.47 \pm 9.0 \text{ kg ha}^{-1}$ and $36.30 \pm 1.4 \text{ kg ha}^{-1}$ in low, intermediate and high-density stand, respectively (Fig. 3c and d).

3.2. Estimates of canopy dynamics

3.2.1. Effective and actual LAI estimates

Leaf area index was taken as LAIe (a direct product from LAI 2200 analyzer), and then the actual leaf area was calculated by multiplying with a correction factor. A significant difference ($F = 11.37$, $p = 0.001$) was observed in the LAI values among different stand densities of Chinese fir. The highest LAI values ($5.072 \pm 0.07 \text{ m}^2 \text{ m}^{-2}$ derived from LAIe of 3.176 ± 0.04) were observed in the high-density stand while the lowest LAI values ($3.974 \pm 0.12 \text{ m}^2 \text{ m}^{-2}$ derived from LAIe of 2.484 ± 0.08) were observed in low density. In intermediate density stand LAI value was $4.561 \pm 0.09 \text{ m}^2 \text{ m}^{-2}$ and the LAIe was 2.484 ± 0.06 (Table 3).

3.2.2. Canopy openness (DIFN) and leaf tilt angle (MTA)

Values in Table 3 exhibited that DIFN varied ($F = 9.839$, $p = 0.001$) among different Chinese fir densities with a wide range between 0.079 and 0.190 (lowest in plot P3 of intermediate density and highest in plot P1 of the low-density stand). On average, the most considerable DIFN value (0.154 ± 0.01) was observed in the low-density stand, while the lowest

Table 3

Observed canopy characteristics of *Cunninghamia lanceolata* stand planted at the low, intermediate and high-density population (competition levels). Different letters within the same row represent significance at $p \leq 0.05$.

Parameter		Competition severity		
		Low	Intermediate	High
		Density-D1	Density-D2	Density-D3
LAI	Plot 1	2.132 \pm 0.05	2.482 \pm 0.08	2.994 \pm 0.05
	Plot 2	2.546 \pm 0.06	2.816 \pm 0.07	3.396 \pm 0.04
	Plot 3	2.782 \pm 0.12	3.252 \pm 0.05	3.148 \pm 0.05
	Average	2.484 \pm 0.08 c	2.851 \pm 0.06 b	3.176 \pm 0.04 a
LAI (m ² m ⁻²)	Plot 1	3.411 \pm 0.08	3.971 \pm 0.12	4.790 \pm 0.08
	Plot 2	4.061 \pm 0.09	4.505 \pm 0.11	4.536 \pm 0.07
	Plot 3	4.449 \pm 0.19	5.203 \pm 0.08	5.036 \pm 0.08
	Average	3.974 \pm 0.12 c	4.561 \pm 0.09 b	5.072 \pm 0.07 a
DIFN	Plot 1	0.190 \pm 0.01	0.147 \pm 0.01	0.102 \pm 0.01
	Plot 2	0.145 \pm 0.02	0.111 \pm 0.01	0.074 \pm 0.01
	Plot 3	0.126 \pm 0.02	0.079 \pm 0.00	0.093 \pm 0.00
	Average	0.154 \pm 0.01 a	0.113 \pm 0.01 b	0.090 \pm 0.01 b
MTA (°)	Plot 1	25.6 \pm 15.0	45.6 \pm 6.0	51.4 \pm 5.8
	Plot 2	33.2 \pm 15.8	42.6 \pm 4.4	45 \pm 3.4
	Plot 3	45.8 \pm 7.8	45.4 \pm 5.2	49.8 \pm 5.6
	Average	34.8 \pm 12.8 b	44.5 \pm 5.3 ab	48.7 \pm 4.9 a
ACF	Plot 1	0.991	0.992	0.994
	Plot 2	0.993	0.994	0.996
	Plot 3	0.986	0.994	0.997
	Average	0.990 a	0.993 ab	0.995 b

Note: Canopy gap fraction was quantified by DIFN values. DIFN Values ranging within interval 0–1; 1 – free area, 0 – full coverage, according to light transmittance method – gap fraction method DIFN is indirectly proportional to LAI.

(0.090 \pm 0.01) was found in the high-density stand. Moreover, the DIFN value in intermediate-density was 0.113 \pm 0.01. DIFN values in both intermediate and high-density stands were significantly different from the low-density stand; however, among the first two, no significant variation was observed. In general trend, values consistently decreased from low to high-density stand (Table 3).

A significant difference ($F = 4.397$, $p = 0.018$) was observed in MTA values among low, intermediate and high-density stands. MTA increased consistently from low density to high density stand and varied from 25.6° (Plot P1 of low-density stand) to 51.4° (Plot P1 of high-density stand). On average, it was observed highest in high-density stand (48.7°) while lowest in low-density stand (34.8°). A linear relationship among LAI-DIFN, LAI-MTA and MTA-DIFN is shown in (Fig. 4).

3.3. Correlation of canopy dynamics, foliar N, soil pH and soil nutrients

Table 4 depicted the correlation among canopy dynamics of Chinese fir different density stands with the leaf nitrogen, soil pH and soil nutrients of respective stands. LAI was positively correlated to leaf N while negatively correlated to tree height, tree DBH and available N. Moreover, no correlation of LAI has observed with soil pH and available P. MTA was positively associated with Leaf N while negatively associated with tree height and DBH. No significant relation of MTA was observed with available N, available P and soil pH. Tree height, DBH and available N positively impacted the DIFN while leaf N was negatively associated. No significant correlation of DIFN was observed with soil pH and available P.

4. Discussion

Worldwide the forest plantations possess highly valued social and ecosystem services (Loehle et al., 2000; Leask et al., 2011). Chinese fir is a needle-leaved species and the canopy growth pattern of the broad-leaved and needle-leaved species is different as the canopy of needle-leaved species grows like an umbrella, opposite to broad-leaved species. Crown morphology varies with various forest management systems (DeRose and Seymour, 2010), and different silvicultural techniques affect the forest canopy structure (Davi et al., 2008; Gonzalez-benecke et al., 2020).

In our study, LAI values vary with varying stand density and consistently increased as stand density increased (Fig. 5). Results from our current study showed a strong relationship between LAI and stand density ($R^2 = 0.797$). In trees of similar age, the phenomena of increment in the LAI with the increasing stand density can be explained by the increase in competition between plants for available light in dense stands. Therefore, in the forest stands with high stem density, the likely explanations of high LAI values are high competition intensity between plants and the ontogeny process. In correspondence with

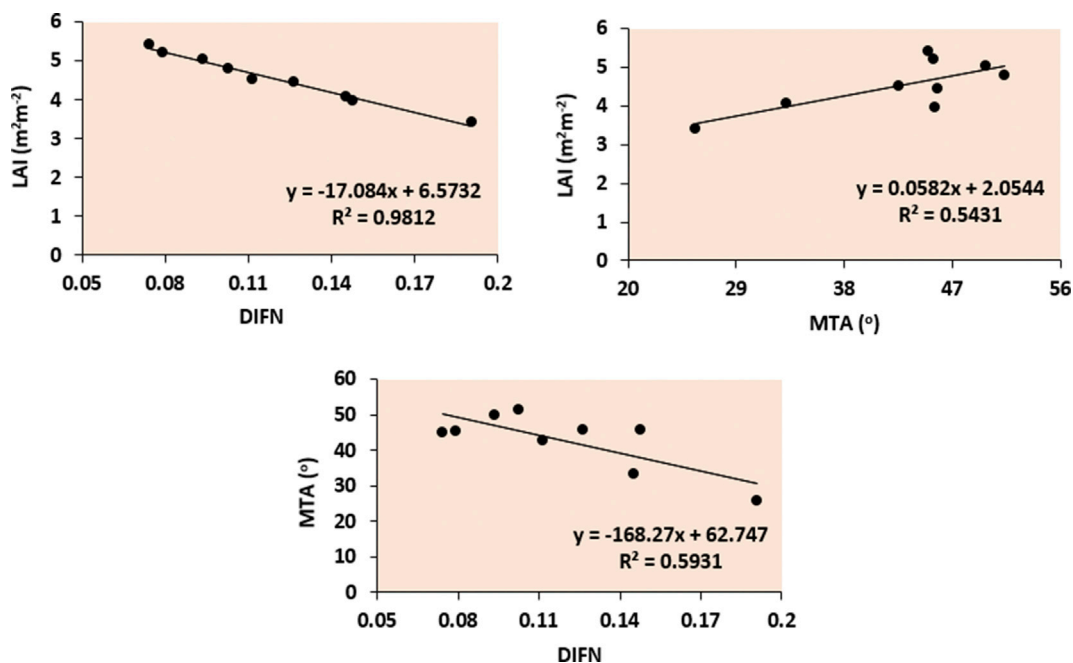


Fig. 4. Relationship between leaf area index (LAI), mean leaf tilt angle (MTA) and canopy openness index (DIFN) independently on stand density.

earlier studies (Bequet et al., 2011), our study revealed a significant relationship between LAI and stem density in Chinese fir plantations. Leaf area will increase up to its peak and then drop slowly as the stand matures and start getting older (Forrester et al., 2013). Our results are in line with (Leuschner et al., 2006; Bequet et al., 2011; Unger et al., 2013), they also reported an increase in LAI values with increasing stem density. In contrast, our results contradict the (McDowell et al., 2007; Kemanian et al., 2004), who stated that LAI was not constant with stand density. Sonohat et al. (2004) also mentioned in his research that leaf area of stand increases with stand development and start declining slowly as stand become older due to increasing self-pruning and tree mortality (Ryan et al., 1997; Meng et al., 2006). In even-aged stands, LAI undergoes gradually and declines continuously after canopy closure. Such a decline of LAI is due to space competition between trees (Pokorný et al., 2008; Nock et al., 2008).

MTA was consistent with stand density and increased as the stand density increased, but the DIFN decreased with the increasing stand density (Fig. 5). However, DIFN was not significantly different in intermediate and high-density stands. This is because, at the initial planting stage, the planting distance between the trees was considerable in the intermediate-density stand as compare to high-density stand but as the stand grows the trees in the intermediate-density stand unfold their canopy more efficiently and grow wider as compare to high-density stands which grow more profound due to short growing space. Light penetration and availability are always high in the trees with fewer neighbors (Gspaltl et al., 2013), as more neighbor trees enhance the competition for growth space and light. The canopy openness in the high-density stand decreased due to self-shading as the higher LAI in high-density stand increases the self-shading. In low-density plantation stands, the crown growth is usually broader as compared to deeper crown growth in the high-density stand. Deeper crowns adjust their light availability when the sun position is near to horizon compared to the broader crown; they adjust when the sun is overhead (Forrester et al., 2013). Increasing stand density enhances the leaf area; in addition to that, it can influence the efficiency of capturing resources by altering the foliage display and crown structure (Gspaltl et al., 2013). Usually, the canopies of the denser stand are uniformly displayed thus capturing of the radiation could be more efficient due to less clumping (Nishimura et al., 2010). For example, with similar leaf area stands of western conifers, the trees with small and shallow crowns were more efficient in capturing light as compared to large trees due to deep canopies. As the stands with larger densities are generally comprised of smaller canopies and minimum heterogeneity, increased growth and LAI values could be attributed to a more efficient display of foliage.

It is generally accepted that trees influence the soil nutrient dynamics under their canopies (Bond-Lamberty et al., 2002). Different studies suggest that macronutrient dynamics altered by the conifers species, primarily when grown in mono-dominant plantations (Zinke, 1962; Vose et al., 1994). Finzi et al. (1998) and Blevins et al. (2005), reported that soil N contents elevated under *Pinus* canopy; this effect can occur on the tree canopy growth. The importance of N for plant growth is highly recognized and N is accepted as a pivotal element for forest structure and productivity (Liu et al., 2018). N deficiency affects the canopy development, which decreases the photosynthetic rate per unit area and leaf area by effecting light interception (Sinclair and Muchow, 1995); low N also affects the leaf size distribution (Valentinuz and Tollenaar, 2006).

Table 4

Correlation analysis of canopy characteristics (LAI, MTA, DIFN) with tree height (TH), tree DBH, available nitrogen (N_A), available phosphorus (P_A), soil pH and foliar nitrogen.

	LAI	MTA	DIFN	TH	DBH	Soil pH	N_A	P_A	Foliar N	LNA
LAI	1									
MTA	.737*	1								
DIFN	-.991*	-.770*	1							
TH	-.734*	-.715*	.724*	1						
DBH	-.734*	-.714*	.723*	.926*	1					
Soil pH	.460	.570	-.540	-.527	-.522	1				
N_A	-.898**	-.648	.914**	.771*	.770*	-.574	1			
P_A	.073	.497	-.098	-.580	-.579	.586	-.223	1		
Foliar N	.760*	.786*	-.780*	-.912**	-.911**	.789*	-.756*	.621	1	
LNA	.635*	.705*	-.688*	-.793*	-.789*	.936**	-.732*	.661	.944**	1

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Note: Values given are the Pearson correlation coefficients. All significant correlations are in mentioned in bold.

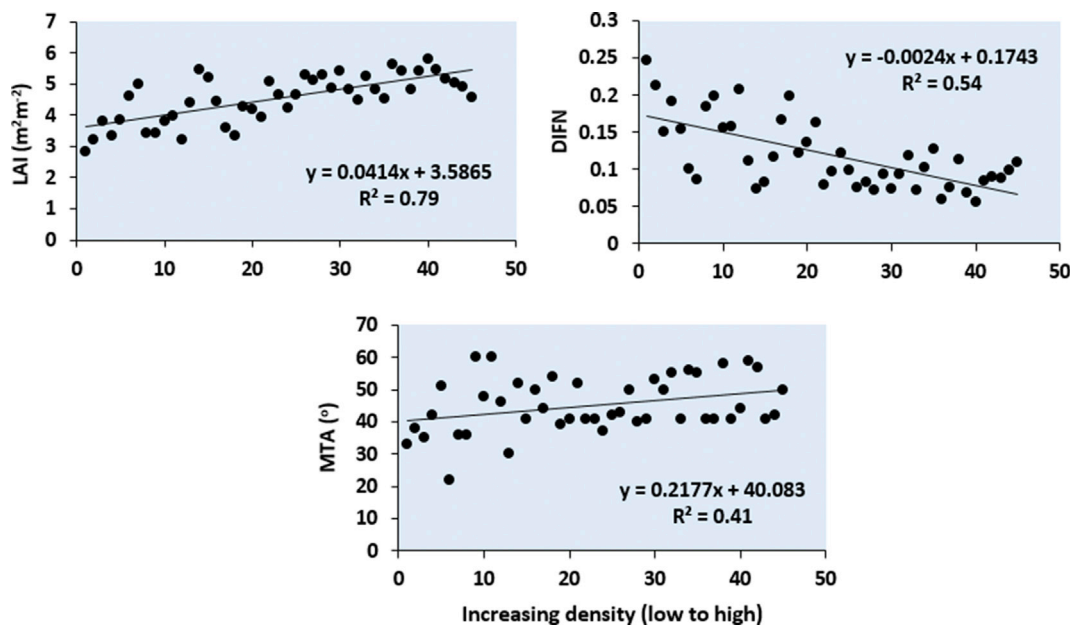


Fig. 5. Trend of association of canopy characteristics; Leaf area index (LAI), Mean tilt angle of the leaf (MTA) and canopy openness index (DIFN) independently with increasing density.

In our study, we observed a significant positive relationship of leaf N with both LAI and MTA. Furthermore, there was a negative correlation found between DIFN and Leaf N. Soil pH and available P was not significant to LAI and MTA; additionally, LAI was negatively correlated to available N. Only DIFN was positively associated to available N. Our study is in line with Unger et al. (2013), who reported that shoot N was positively related to canopy growth parameters while soil elements played a secondary role in canopy dynamics structuring. Different researchers reported that LAI decrease as the stand grows old, it can be explained with the fact that, shoot N concentration in dense canopies declines as the stand grows even with the sufficient supply of N. As the average N allocation in leaves is not uniform and generally parallels to the light distribution. As dense canopy develops, a higher proportion of the leaves didn't get enough light; thus N concentration within the canopy decreases (Rossini et al., 2011; Forrester et al., 2013; Iames et al., 2018).

Canopy factors like light interception and distribution can be modified by different management factors such as adjusting planting density and orientation, row to row spacing and tree genetic factors that influence plant architecture (Bond-Lamberty et al., 2002; Timlin et al., 2014). Several forest management concepts encourage the creation of complex canopies structures, avoiding simple even-aged stands (Puettmann et al., 2015). Our research provides a perspective about the functional role of stand density on the canopy dynamics concerning to soil chemical properties and leaf N. This research provides the base about the effects of varying stand densities in young to mid-age *Cunninghamia lanceolata* plantations; this paved the way for research at the mature stage of the forest as more senescence activities would take place in old age stands.

5. Conclusions

Canopy dynamics appear to be valuable parameters for evaluating the growth status of a forest stand. Varying stand density and spacing strongly influence the canopy structure and associated leaf area. Stand density was the main factor responsible for altering canopy growth, and LAI and MTA in the Chinese fir plantation stand increased consistently as the stem density increased. DIFN decreased with increasing density, but there was no significant difference observed in intermediate and high-density stands. A positive correlation of canopy dynamics was observed with leaf N while overall, soil pH and soil nutrients were not significant to canopy dynamics. Soil fertility doesn't significantly associate with canopy dynamics in varying densities. Along with the advanced LAI-2200 canopy analyzer, for a three-dimensional study of forest canopy, airborne and terrestrial laser scanning systems could also be used for studying canopy distribution patterns.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Abbreviations

LAI	Leaf area index
LAI _e	Effective leaf area index (direct product of LAI-2200)
DIFN	Diffuse Non-interceptance
MTA	Mean tilt angle of the leaf
ACF	Apparent clustering factor
PH	Plant height
PCA	Plant canopy analyzer
LNC	Leaf nitrogen concentration
LND	Leaf nitrogen distribution

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